Carbon Monoxide-Related Hospitalizations in the U.S.: Evaluation of a Web-Based Query System for Public Health Surveillance

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SYNOPSIS

Objective. Carbon monoxide (CO) poisoning is preventable, yet it remains one of the most common causes of poisoning in the U.S. In the absence of a national data reporting system for CO-poisoning surveillance, the burden of CO-related hospitalizations is unknown. Our objective was to generate the first national estimates of CO-related hospitalizations and to evaluate the use of a Web-based query system for public health surveillance.

Methods. The Healthcare Cost and Utilization Project's (HCUP's) 2005 Nationwide Inpatient Sample (NIS) data were used for CO-related hospitalization estimates. Data for confirmed, probable, and suspected cases were generated using the HCUPnet Web-based query system. We used data from 1993 through 2005 NIS to describe trends in CO-related hospitalizations. We used the Centers for Disease Control and Prevention's surveillance evaluation guidelines to evaluate the system.

Results. In 2005, there were 24,891 CO-related hospitalizations nationwide: 16.9% (n=4,216) were confirmed, 1.1% (n=279) were probable, and 81.9% (n=20,396) were suspected CO-poisoning cases. Of the confirmed cases (1.42/100,000 population), the highest hospitalization rates occurred among males, older adults (aged ≥85 years), and Midwestern residents. CO-related hospitalization rates declined from 1993 through 2000 and plateaued from 2001 through 2005. The simplicity, acceptability, sensitivity, and representativeness of the HCUPnet surveillance system were excellent. However, HCUPnet showed limited flexibility and specificity.

Conclusions. Nationwide, the burden of CO exposure resulting in hospitalization is substantial. HCUPnet is a useful surveillance tool that efficiently characterized CO-related hospitalizations for the first time. Public health practitioners can utilize this data source for state-level surveillance.

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Unintentional, non-fire-related (UNFR) carbon monoxide (CO) poisoning is one of the most common causes of poisoning in the United States. It results in more than 20,000 emergency room visits annually.[1] CO poisoning is a preventable condition, yet it was responsible for nearly 450 unintentional deaths annually during the period 1999 through 2004.[2] Because of the magnitude of the problem, *Healthy People 2010* listed CO-poisoning surveillance as one of its environmental health priority areas.[3]

CO is produced as a consequence of the incomplete combustion of hydrocarbons. Major sources of CO include motor vehicle exhaust, generators, and other fuel-burning equipment; poorly maintained, poorly functioning, or unventilated heating and cooking appliances (e.g., kerosene and gas space heaters, woodstoves, fireplaces, gas stoves, boilers, and furnaces); and other occupational sources.[4,5] UNFR CO poisoning is often underdiagnosed because of its nonspecific symptoms.[1,6] Low-level CO exposure can cause such flu-like symptoms as fatigue, headache, dizziness, nausea, vomiting, and confusion, while high-level exposure can cause more severe effects such as disorientation, collapse, coma, cardiorespiratory failure, and death.[7,8] Approximately 15% to 49% of those who experience CO poisoning develop neurocognitive sequelae, including impaired memory and executive functions.[9–12]

Several datasets, including the National Vital Statistics System, the National Electronic Injury Surveillance System–All Injury Program (NEISS-AIP), and reports from hyperbaric oxygen treatment facilities, are currently used for national CO-related mortality and morbidity surveillance.[1,2,13] No national data reporting system is currently in place for CO-related hospitalizations; thus, the complete burden of CO poisoning is unknown. Because hospitalized cases are more likely to represent severe CO exposures, hospitalization data are needed to understand the magnitude and distribution of such exposure and to develop targeted public health prevention messages. We used the Agency for Healthcare Research and Quality's (AHRQ's) Healthcare Cost and Utilization Project (HCUP) Web-based query system (HCUPnet) to generate the first national estimates of UNFR CO-related hospitalizations. In addition, we evaluated HCUPnet as a public health surveillance system for CO-related hospitalizations, using the Centers for Disease Control and Prevention's (CDC's) surveillance evaluation guidelines.[14]

METHODS

Data source and description

HCUP is a nationwide information resource for patient care data developed through federal-state partnerships and sponsored by AHRQ. The basis of HCUP data is hospital discharge information from community hospitals in partner states. Community hospitals are defined as nonfederal, short-term general hospitals and other specialty hospitals (e.g., obstetrics and gynecology, orthopedic, and pediatric) excluding federal, psychiatric, rehabilitation, long-term, and tuberculosis hospitals. Also excluded are prison hospitals and institutional hospitals such as college infirmaries.[15] Hospitals in participating states send billing information and additional data elements to their respective data organizations that perform quality checks on the data received. State-level data are sent to AHRQ, where they undergo further standardization and internal consistency checks before being stored in state-specific databases. Data on hospital stays, emergency department (ED) visits, and ambulatory surgical care are stored in separate databases.[15] The Nationwide Inpatient Sample (NIS) is a stratified (approximately 20%) probability sample of community hospitals drawn from the combined pool of the HCUP state-specific hospitalization databases. Hospital stratification is based on geographic region (Northeast, Midwest, West, or South), hospital ownership (public, private nonprofit, or proprietary), location (metropolitan or nonmetropolitan), teaching status (yes or no), and bed size (small, medium, or large). All discharges from the sampled hospitals are retained in the NIS. Stratum-specific weights are applied to NIS data to produce nationally representative estimates.

Hospital discharge data from 37 states were included in the 2005 NIS. The 2005 NIS sampling frame included more than 95% of all eligible hospitals from 31 participating states and approximately 60% to 83% of all eligible hospitals from six other states (Hawaii, Texas, Ohio, Michigan, South Carolina, and South Dakota). Nationally, the sampling frame comprised 75% of all U.S. hospitals including approximately 87% of all hospitals from the Midwest, 77% of those from the West, 69% of those from the South, and 63% of those from the Northeast. The final 2005 NIS sample included 1,054 hospitals and data from nearly eight million discharges.[16]

HCUPnet is a free, publicly available, online tool that generates estimates based on HCUP databases. A step-by-step query system allows HCUPnet users to explore data by year, type of hospital admission (i.e., inpatient or ED visit), discharge status, sociodemographic and hospital stay characteristics, and diagnoses based on International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes.[17] We obtained data from the 2005 NIS data files using the HCUPnet query system (available at http://hcupnet.ahrq.gov). The data source and flow for HCUPnet are illustrated in Figure 1.

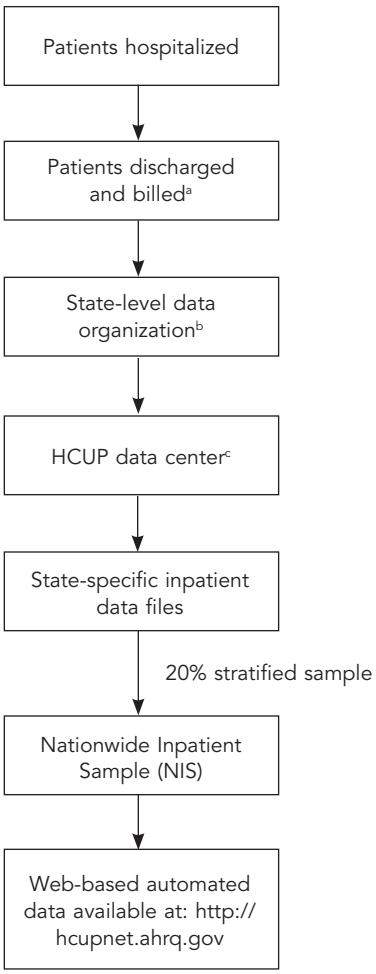
Case definition

The Council of State and Territorial Epidemiologists (CSTE) offers an updated definition of CO poisoning that is based on ICD-9-CM codes; we used this definition to classify confirmed, probable, and suspected case types.[18] As the public health prevention approach of intentional and fire-related CO exposures is different from that of UNFR CO exposures, we excluded intentional and fire-related ICD-9-CM codes for CO poisoning from our analysis. Cases were included and categorized into specific case types based on whether any of the following codes were listed in any diagnosis (e.g., primary, secondary, or tertiary) fields:

1. Confirmed cases: ICD-9-CM code 986—Toxic effect of carbon monoxide, or external cause-of-injury codes (E-codes) indicating CO exposure (E868.3, E868.8, E868.9, and E982.1)
2. Probable cases: E-codes indicating acute CO poisoning inferred from exposure to motor vehicle exhaust (E868.2 and E982.0)
3. Suspected cases: E-codes that mention CO exposure (E818.0–818.9, E825.0–825.9, E844.0–844.9, E867, E868.0, and E868.1) or E-codes where CO exposure is plausible (E838.0–838.9, E869.9, E981.0, E981.1, and E981.8)

We reported estimates for all case types, but only analyzed the confirmed cases further, under the assumption that they more accurately represented the CO-related hospitalization burden.

Figure 1. HCUPnet data sources and flow



[a]Includes assignment of International Classification of Diseases, Ninth Revision, Clinical Modification codes for diagnoses and procedures

[b]Includes data quality check

[c]Includes data standardization, internal consistency check, and other quality-control procedures

HCUPnet = Healthcare Cost and Utilization Project's Web-based query system

HCUP = Healthcare Cost and Utilization Project

Statistical analysis

We used automated query functions on the HCUPnet website (http://hcupnet.ahrq.gov) to generate UNFR CO-poisoning hospitalization data, including frequencies and proportions. HCUPnet allows queries based on either "Principal diagnosis" or "All listed diagnoses." By convention, HCUP includes E-codes as secondary diagnoses (Personal communication, HCUP user support, September 2007). Thus, analysis of CO poisoning as a principal diagnosis could be assessed only by using code "986—Toxic effects of carbon monoxide," which is not an E-code.

To generate estimates for confirmed, probable, and suspected cases of CO poisoning, we entered corresponding ICD-9-CM codes into the "All listed diagnoses" box (e.g., for confirmed cases, we entered 986, E868.3, E868.8, E868.9, and E982.1), and specified relevant person and place characteristics. We generated separate estimates for cases where CO poisoning was listed as the principal diagnosis by entering "986—Toxic effects of carbon monoxide" into the "Principal diagnosis" box and specifying relevant person and place characteristics.

HCUPnet provides hospitalization data for individual years from 1997 onward. However, analysis of overall annual trends could be performed on data from 1993. Trends in annual rates of hospitalization for confirmed CO-poisoning cases were generated entering ICD-9-CM codes for confirmed cases (i.e., 986, E868.3, E868.8, E868.9, and E982.1) into the "All listed diagnoses" box.

HCUP used SUDAAN® software[19] to weight data and to generate standard error estimates.[17] Estimates with

a relative standard error of 0 or >0.30 were deemed unreliable and were suppressed by the automated query system. Values based on ≤10 discharges nationwide were also suppressed.[20] We calculated age- and gender-specific rates on the basis of the National Center for Health Statistics' censal and post-censal bridged-race population estimates.[21] For regional rates, we used the U.S. Census Bureau population estimates.[22]

Surveillance evaluation

In 2001, CDC updated its guidelines for public health surveillance system evaluation.[14] In accordance with the guidelines, we have used the criteria of simplicity, flexibility, data quality, acceptability, sensitivity, predictive value positive (PVP), representativeness, timeliness, stability, and usefulness to evaluate HCUPnet as a surveillance system for UNFR CO-related hospitalizations. Based on the evaluation of each criterion, the authors collectively ranked them as excellent, good, or fair. Evaluation of a surveillance system may include system implementation and intricacies of data infrastructure, but because HCUPnet is already set up as an outlet to HCUP data, the surveillance evaluation was conducted from a data-user perspective rather than a system implementation perspective.

RESULTS

CO-related hospitalizations

Based on "All listed diagnoses," 24,891 hospitalizations were associated with UNFR CO poisoning in 2005, of which 16.9% (n=4,216) were confirmed, 1.1% (n=279) were probable, and 81.9% (n=20,396) were suspected cases. The hospitalization rate was 8.40/100,000 population for all case types and 1.42/100,000 population for confirmed cases (Table 1). Among the confirmed cases, "986—Toxic effects of carbon monoxide" was the most commonly listed diagnosis (74.6%) followed by "E868.8—Carbon monoxide from other sources" (11.9%) and "E868.9—Unspecified carbon monoxide" (6.0%) (Table 2). Approximately 42.1% (0.60/100,000 population) of the confirmed cases had "986—Toxic effects of carbon monoxide" listed as the principal diagnosis (Table 1).

Most of the confirmed case subjects were male (59.9%) and aged ≥45 years (57.0%). Private insurance (32.5%), Medicare (25.3%), and Medicaid (19.5%) were the expected sources of payment for most confirmed cases; however, 15.6% of CO-poisoning patients were uninsured and 7.0% had other means of payment. Most patients resided in small or large metropolitan areas (74.2%) and were hospitalized in metropolitan cities (83.5%). Nearly one-third (32.6%) of patients lived in the South, followed by the Midwest (30.7%), Northeast (23.1%), and West (13.8%).

Hospitalization rates increased with age, and adults aged ≥85 years had the highest rate (3.04/100,000 population). The rate of hospitalization was 50% greater among males (1.73/100,000) than among females (1.12/100,000 population). Geographically, the Midwest and Northeast regions had the highest hospitalization rates, while the West had the lowest.

An analysis of annual trends revealed that CO-related hospitalization rates declined from 1993 to 2000 and plateaued from 2001 to 2005 (Figure 2).

Evaluation of HCUPnet

The results of the evaluation of HCUPnet as a surveillance system for UNFR CO-related hospitalizations are summarized in Figure 3.

Simplicity. Operational ease and system structure are two of the parameters that determine the simplicity of a surveillance system.[14] Procurement and analysis of surveillance data is often a time-consuming and resource-intensive process. However, operation of HCUPnet is straightforward; it allows for generating data without complex handling and requires a minimal investment of such resources as time and financing. HCUPnet functions efficiently on a typical computer with Internet access and quickly retrieves data. The system guides the user through a straightforward, step-by-step process to generate data, and it requires only minimal statistical and computing expertise.

System structure may be of greater significance to those building or maintaining the data infrastructure than it is for data users obtaining information from it. Consequently, the multilayered complex structure of the HCUP data system (as illustrated in Figure 1) is likely to have little impact on the surveillance personnel obtaining data from HCUPnet.

Flexibility. The flexibility of a surveillance system depends on its ability to adapt to new data demands and operations.[14] Person and place data are integral to a surveillance system. HCUPnet provides information on person (age group, gender, and payer information) and place (region of the U.S. and metropolitan area) variables, as well as additional health data (length of stay, hospital charges, discharge status, and source of admission). Numeric and graphical trend analyses on hospitalizations by person and place subgroups can be performed on data from 1993 through 2005. HCUPnet includes ICD-9-CM codes for all diagnoses and procedures. Any changes in the current CO-poisoning case definitions, which are based on ICD-9-CM codes, can be readily adapted in the query system.

Table 1. Characteristics of confirmed CO-poisoning hospitalization cases in the U.S. in 2005 (*n*=4,216)

Variables	N *(percent)*	*Rate (95% CI) per 100,000*
All confirmed cases	4,216 (100.0)	1.42 (1.38, 1.47)
Principal diagnosis (ICD-9-CM code 986)	1,776 (42.1)	0.60 (0.57, 0.63)
Age (in years)		
<1	NA[a]	NA[a]
1–17	341 (8.1)	0.49 (0.44, 0.54)
18–44	1,442 (34.2)	1.27 (1.21, 1.34)
45–64	1,499 (35.6)	2.06 (1.95, 2.16)
65–84	745 (17.7)	2.35 (2.18, 2.52)
≥85	155 (3.7)	3.04 (2.56, 3.52)
Gender		
Male	2,525 (59.9)	1.73 (1.66, 1.80)
Female	1,682 (39.9)	1.12 (1.06, 1.17)
Payer information		
Medicare	1,066 (25.3)	NA[b]
Medicaid	823 (19.5)	NA[b]
Private	1,371 (32.5)	NA[b]
Uninsured	658 (15.6)	NA[b]
Other	294 (7.0)	NA[b]
Place of residence		
Large metropolitan	1,779 (42.2)	NA[b]
Small metropolitan	1,350 (32.0)	NA[b]
Non-metropolitan	1,058 (25.1)	NA[b]
Region		
Northeast	975 (23.1)	1.78 (1.67, 1.90)
Midwest	1,295 (30.7)	1.96 (1.86, 2.07)
South	1,364 (32.6)	1.27 (1.20, 1.34)
West	582 (13.8)	0.85 (0.78, 0.92)

[a]HCUP suppresses values less than 10 for some variables and values with a relative standard error of 0 or >0.30.

[b]Rates are not provided because population denominator data were not available for these variables.

CO = carbon monoxide

CI = confidence interval

ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification

NA = not available

HCUP = Healthcare Cost and Utilization Project

Despite the system's demonstrated flexibility, the query approach to gathering surveillance data inherently lacks the capacity to analyze information firsthand. Preset queries precluded the exclusion of some E-codes that can occur simultaneously with other codes and may have resulted in duplicate case counts. When using ICD-9-CM codes to select cases, HCUPnet does not provide two-way tables of person and place characteristics. Some data elements, such as race and date of admission or discharge, are not available through HCUPnet; therefore, these variables could not be analyzed. However, the NIS data and state-specific inpatient and ED data are commercially available through HCUP; they can provide users with more control and flexibility over data analysis and presentation.

Data quality. Completeness and validity are two components of data quality.[14] Among the 4,216 confirmed CO-poisoning cases reported in 2005, completeness (percent not missing) of data fields was 100% for region, teaching status, location, and bed size; >99% for age, gender, payer, and patient residence; and 95% to 99% for hospital type and median zip-code income. In terms of validity, data retrieved from HCUPnet are only as good as the data received from hospitals and states. The errors resulting from variability or mistakes in ICD-9-CM coding at the hospitals or state-level data organizations could not be ascertained in this evaluation. However, at the HCUP data center, each discharge record undergoes automated quality-control procedures to assess the validity of data elements as

Table 2. Frequency of confirmed CO-poisoning hospitalization cases by specific ICD-9-CM codes in the U.S. in 2005 (*n*=4,216)

ICD-9-CM code	*Description*	N *(percent)*
986	Toxic effect of carbon monoxide	3,147 (74.6)
E868.3	Carbon monoxide from incomplete combustion of other domestic fuels Carbon monoxide from incomplete combustion of: Coal in domestic stove or fireplace Coke in domestic stove or fireplace Kerosene in domestic stove or fireplace Wood in domestic stove or fireplace Excludes: carbon monoxide due to smoke and fumes due to conflagration (E890.0–E893.9)	172 (4.1)
E868.8	Carbon monoxide from other sources Carbon monoxide from: Blast furnace gas Incomplete combustion of fuels in industrial use Kiln vapor	501 (11.9)
E868.9	Unspecified carbon monoxide	252 (6.0)
E982.1	Poisoning by other gases, undetermined whether accidentally or purposely inflicted—other carbon monoxide	144 (3.4)

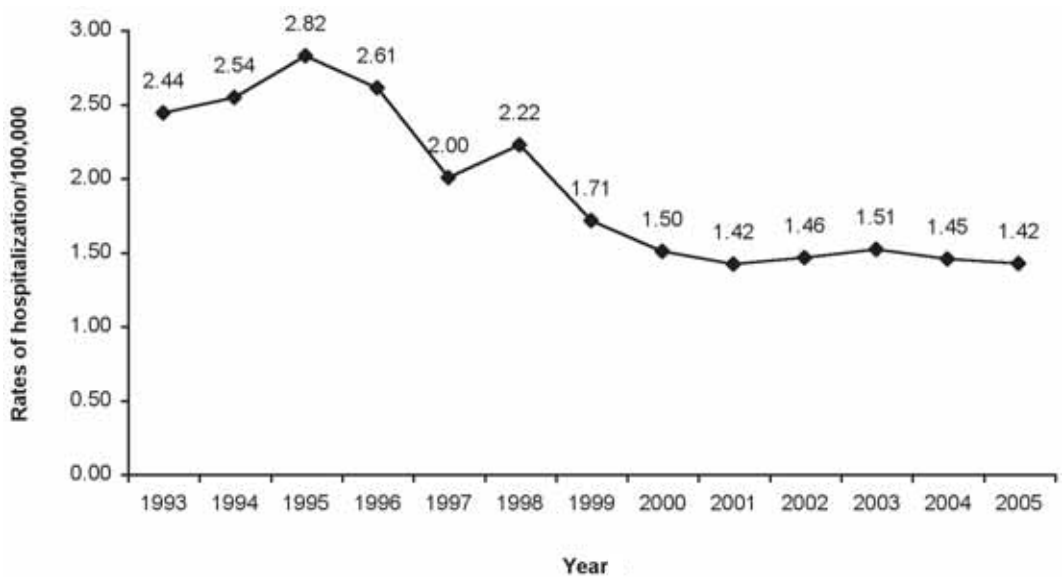
CO = carbon monoxide

ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification

compared with acceptable values (e.g., age range 0–124 years and non-negative length of stay) and to assess the internal consistency between data elements (e.g., gender of patient corresponds with type of procedure, or discharge occurs after admission date).[23] Invalid and inconsistent data elements are set to a special missing value to indicate an edit failure. The number of edit failures is computed annually as a quality review of each data source. In the 2005 NIS, <0.05% of records had a principal diagnosis of questionable validity and 2.50% of injury-related records had either an invalid E-code (<0.01%), a missing E-code (1.50%), or an E-code with no injury-related diagnosis (1.00%).[24]

Acceptability. The willingness of states to contribute data determines the acceptability of a surveillance system.[14] In 1988, NIS included data from 1,247 community

Figure 2. Carbon monoxide-related hospitalization rates, U.S., 1993–2005[a]



[a]Source: Healthcare Cost and Utilization Project's 2005 Nationwide Inpatient Sample data

hospitals in eight partner states on approximately 5.2 million discharges. In 2005, those numbers had grown to 3,860 hospitals in 37 states and nearly eight million discharges.[16] The number of participating states continues to increase, with 38 states participating in 2006.[25] Conversely, only three states had discontinued data contribution to HCUP as of 2005.[16]

Sensitivity and PVP. Both sensitivity and PVP measure how well a surveillance system captures true cases of a health-related event.[14] For this evaluation, sensitivity is the proportion of true CO-related hospitalizations detected by HCUPnet, and PVP is the proportion of CO-related hospitalizations reported by HCUPnet that are true cases. In the absence of a set "gold standard" for CO-poisoning diagnosis and lack of access to actual discharge data, sensitivity of HCUP data for UNFR CO poisoning could not be ascertained directly. However, two factors indirectly suggest that HCUP data should have high sensitivity. First, E-code reporting for injury cases is more complete in HCUP databases than it is in other nationally representative datasets. For example, in the 2001 NIS, 86.0% of injury diagnoses had an E-code, compared with 68.0% in the 2001 National Hospital Discharge Sample (NHDS) dataset.[26] In the 2005 NIS, only 1.5% of injury diagnoses did not have an associated E-code.[24] Second, the HCUP database includes up to 15 diagnoses and four E-code fields in which to identify possible CO-related hospitalizations. However, as a result of the many secondary diagnoses and E-codes, the CO-specific codes in these fields might not represent the primary cause of hospitalization for some cases. This will decrease the specificity of the data and subsequently lower the PVP.

Representativeness. Representativeness refers to the HCUPnet's ability to accurately describe CO-poisoning hospitalizations by person, place, and time.[14] The 2005 NIS sampling frame represented 78% of U.S. community hospitals, 84% of community hospital discharges, and 86% of the U.S. population. The NIS weighted data for total hospital discharges closely approximated that of the NHDS in terms of hospital and patient characteristics, diagnoses, procedures, and length of stay.[27] Thus, the NIS weighted data provided in HCUPnet are largely representative of U.S. hospitalizations. Population-wise, states participating in the 2005 NIS represented 99% of the population in the Midwest, 92% in the West, 81% in the South, and 75% in the Northeast region of the U.S.[16]

Timeliness. Traditionally, the timeliness of a surveillance system is determined by the period between each data step within the system.[14] However, from the perspective of surveillance personnel, it might be more relevant to address timeliness as the period of time that passes between data collection and public release. Similar to many national datasets available to the public, the HCUPnet system has a lag time of one and a half years. For example, HCUPnet NIS data for 2005 were available in June 2007.[28]

Stability. The stability of a surveillance system reflects the availability and reliability of the data.[14] HCUP has been receiving data since 1988, and HCUPnet has been available to the public since 1999 (Written communication, HCUP user support, September 2008). Also, data are accessible 24 hours a day on the HCUPnet website. HCUP is funded through congressional allocation on an annual basis.[29] This longstanding

Figure 3. Summary of surveillance system evaluation for HCUPnet[a]

System attribute	*Attribute definition*	*Rank*
Simplicity	System ease of use and design	Excellent
Flexibility	Ability to adapt to changing needs	Fair
Data quality	Completeness and validity of data fields	Good
Acceptability	Participant willingness	Excellent
Sensitivity	Proportion of true cases reported to system	Excellent
Predictive value positive	Proportion of reported cases that are true cases	Fair
Representativeness	Population representation by person, place, and time	Excellent
Timeliness	Period between each step in the system	Fair
Stability	System reliability and availability	Good
Usefulness	Improves prevention or understanding of health-related events	Good

[a]Adapted from the Centers for Disease Control and Prevention's (CDC's) Updated Guidelines for Evaluating Public Health Surveillance Systems, 2001. (Source: German RR, Lee LM, Horan JM, Milstein RL, Pertowski CA, Waller MN; Guidelines Working Group, CDC [US]. Updated guidelines for evaluating public health surveillance systems: recommendations from the Guidelines Working Group. MMWR Recomm Rep 2001;50[RR-13]:1-35.)

HCUPnet = Healthcare Cost and Utilization Project's Web-based query system

infrastructure contributes to the stability of the data system.

Usefulness. The usefulness of a public health surveillance system is determined by its contribution to the prevention, control, and understanding of a health-related event.[14] Overall, HCUPnet proved to be highly useful as a surveillance system for UNFR CO-related hospitalizations—a health event for which surveillance data were previously unavailable. It provided data on the nationwide burden of CO-related hospitalizations for the first time, thus filling a major data gap in CO-poisoning surveillance.

CO-related hospitalization data are not available from other datasets that are currently used for nationwide CO-poisoning surveillance (e.g, NEISS-AIP, hyperbaric oxygen treatment data, or Poison Control Center data). Also, a larger national probability sample as compared with the NHDS enabled more reliable and precise estimates of the national UNFR CO-related hospitalization burden. These two factors make HCUPnet a unique data source for national UNFR CO-related hospitalization surveillance.

The query system allowed for accurate implementation of CSTE case definitions for CO poisoning by use of ICD-9-CM codes. The user is also allowed to conduct a trend analysis on CO-related hospitalizations from 1993 onward. These trends can be used as an indicator of the overall success of public health prevention efforts to reduce UNFR CO exposures. HCUPnet meets the criteria of a useful public health surveillance system because it is both ongoing and systematic.[14,30] Data generated through this system can provide guidelines for prevention efforts and policy recommendations for severe CO poisoning.

Routine data collection, periodic data release, and continuous data availability add to the consistency and strength of HCUPnet. Ease of operation from the user perspective and continuous availability of a large repository of hospital discharges make HCUPnet a useful public health utility tool, especially when resources are limited and the demand for data is immediate. It is possible that the scope of use for HCUPnet can be extended beyond UNFR CO-poisoning surveillance, and the usefulness of HCUPnet for other specific health outcomes should be evaluated separately.

DISCUSSION

This study provided the first national estimates of UNFR CO-related hospitalization. In 2005, there were 4,216 hospitalizations (1.42/100,000 population) classified as confirmed cases of CO poisoning and 24,891 hospitalizations (8.40/100,000 population) with at least one CO-related ICD-9-CM code listed as a diagnosis. These estimates suggest that a substantial number of hospitalized cases resulting from CO exposure are not currently accounted for, as there is no surveillance system in place that includes CO-related hospitalizations.

In addition, HCUPnet provided preliminary data on the economic burden of these hospitalizations, which has also gone unrecognized until now. Hospital charge data were available for cases with a principal diagnosis of CO poisoning. The total hospital charges for cases where the principal diagnosis was "986—Toxic effects of carbon monoxide" was nearly $27 million (mean = $15,168; median = $7,613) in 2005 (data not shown). These amounts do not include professional fees (e.g., physician) or reflect the total amount reimbursed. In this study, ICD-9-CM code 986 as the principal diagnosis comprised only 42% of all cases. Therefore, the overall cost burden of CO-related hospitalization is much higher than this estimate.

Overall, the rate of hospitalization increased with age and was higher among males. These population subgroups (males and older adults) are similar to those at the highest risk for CO-related mortality;[2] however, they are different from the subgroups at highest risk for CO-related ED visits, in which females and children aged ≤4 years are more often affected.[1] Children could be more susceptible to CO poisoning due to higher basal metabolic rate and tissue oxygen demand.[31] However, they are expected to manifest symptoms early and to recover more quickly because of higher minute ventilation per unit of body mass.[32] Women also manifest symptoms at lower levels of exposure because of lower red-blood-cell count.[33] These factors may lead to earlier exposure recognition and, therefore, a lower exposure and shorter recovery time.

As with mortality risk, it could be assumed that a higher hospitalization rate among men may be due to engagement in high-risk behaviors, such as using fuel-burning tools or appliances. It has been suggested that severe CO exposures among the older adult population could be due to the misidentification of CO-related symptoms as fatigue or flu-like illnesses.[2] However, whether older adults and male populations are more severely poisoned, leading to higher hospitalization and mortality rates, requires further investigation.

CO exposures typically follow a seasonal pattern in which both fatal and nonfatal rates peak during the winter season; this peak is likely due to an increase in high-risk behaviors, such as generator use, exposure to automobile exhaust by stranded motorists during and after winter storms, indoor use of grills or stoves, and improper maintenance of home heating systems.[1,2,34]

Observed regional patterns may be explained by weather differences across regions. For example, long and severe winter seasons and the subsequent increase in the aforementioned high-risk behaviors may have contributed to the higher rates of CO-related hospitalization in the Midwest and Northeast regions of the U.S.

The proportion of uninsured patients was higher for CO-related hospitalizations (15.6%) than for overall hospitalizations (5.3%) in the 2005 NIS (data not shown). Whether severe CO exposures disproportionately affect those with limited access to health care or low socioeconomic status warrants further investigation. Also, we do not know whether there is a difference between urban and rural CO-poisoning rates in the U.S. In this study, 74% of the confirmed cases were residents of either large or small metropolitan areas. This distribution is similar to the U.S. population distribution (79% urban and 21% rural), according to the 2000 Census.[35]

Examination of CO-related hospitalization trends revealed a decline in the rate of confirmed cases from 1993 through 2001, followed by a plateau from 2001 through 2005. This trend is important from a public health perspective, as it suggests that existing public health initiatives and efforts need to be continued and reinforced to further decrease the number of UNFR CO exposures.

Limitations

Some limitations should be taken into account while interpreting the results from this study. CO-related hospitalization estimates obtained from HCUPnet could be an underestimation of total hospitalizations because they do not account for cases seen in federal or other hospitals that are excluded from the NIS sampling frame. Additionally, some injury cases without any listed E-codes were not included in our analysis.[24] On the contrary, limitations of the query system might have led to duplicate case counts and the inclusion of some intentional and fire-related cases, primarily because of the complex exclusion criteria of the case definition. Also, we were unable to determine the overall effect of variable E-coding rates and practices by different states and hospitals.

HCUP quality-control procedures exclude similar E-codes for the same injury event—i.e., if a case has multiple CO-related E-codes listed in the diagnosis, all but one E-code would be removed to avoid duplicate counts (Personal communication, HCUP user support, November 2007); however, CO-related E-codes, including fire-related and intentional E-codes, may still be recorded for some cases when ICD-9-CM code 986 is listed as the principal diagnosis because 986 is not an E-code. This is a major limitation of using HCUPnet for UNFR CO-poisoning hospitalization surveillance.

Finally, some relevant data elements, such as dates of hospitalization and length of stay, are not available for any diagnoses other than the principal diagnosis. Information on place of CO exposure occurrence provides an opportunity for the development of public health prevention strategies. HCUP data do not include the place-of-occurrence data. Also, they do not include information on workers' compensation; this limits analysis of work-related CO-poisoning cases. Including additional queries and data elements, and expanding HCUP partner states will make HCUPnet a formidable public health data repository. Further, given that adequate resources are available, many of these limitations can easily be overcome by analysis of commercially available HCUP data.

CONCLUSIONS

The HCUP database is the largest compilation of hospital discharge data in the U.S. The data have been standardized and uniformly coded across all partner states. The database includes information on all payers, including the uninsured.[15] The evaluation of HCUPnet suggests that this system is sensitive, inexpensive, simple, stable, and drawn from a nationally representative sample of hospital discharges. Surveillance systems that manifest these qualities are considered useful for public health action.[14] A large sample size that allows for more precise estimates, smaller sampling error, and the nationwide representation of the data further accentuates the utility of HCUPnet. Previously, a wide range of scientific articles on cancer, cardiovascular disease, neurological disorders, mental health, mortality, health-care access and utilization, and disparities have been published based on HCUP data.[36]

The HCUPnet query system can be a valuable resource for disease surveillance and public health program planning. With advances in technology, researchers and public health practitioners are inventing novel approaches to obtain data and address public health issues. Electronic surveillance systems can provide estimates for program planning with minimal resource utilization. Such a feature can be of particular significance to state health departments with resource constraints, for HCUPnet offers data on state-specific hospitalizations and ED visits for participating states. The HCUPnet query system can be adopted for surveillance of other diseases and conditions, resulting in a considerable conservation of resources.

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REFERENCES

1. Nonfatal, unintentional, non-fire-related carbon monoxide exposures—United States, 2004–2006. MMWR Morb Mortal Wkly Rep 2008;57(33):896-9.
2. Unintentional poisoning deaths—United States 1999–2004. MMWR Morb Mortal Wkly Rep 2007;56(5):93-6.
3. Department of Health and Human Services (US). Healthy people 2010: volume 1. 2nd ed. Objectives for improving health, focus area 8: environmental health. Objective 8-27h: carbon monoxide poisoning [cited 2008 Sep 10]. Available from: URL: http://www.healthypeople.gov/Document/HTML/Volume1/08Environmental.htm#_Toc490564711
4. Ernst A, Zibrak JD. Carbon monoxide poisoning. N Eng J Med 1998;339:1603-8.
5. Environmental Protection Agency (US). Indoor air quality: basic information: carbon monoxide (CO) [cited 2008 Sep 16]. Available from: URL: http://www.epa.gov/iaq/co.html
6. Wright J. Chronic and occult carbon monoxide poisoning: we don't know what we're missing. Emerg Med J 2002;19:386-90.
7. The National Workgroup on Carbon Monoxide Surveillance. Carbon monoxide: a model environmental public health indicator [cited 2008 Sep 17]. Available from: URL: http://www.maine.gov/dhhs/eohp/epht/documents/CO_WHITE.pdf
8. Raub JA, Mathieu-Nolf M, Hampson NB, Thom SR. Carbon monoxide poisoning—a public health perspective. Toxicology 2000;145:1-14.
9. Myers RA, DeFazio A, Kelly MP. Chronic carbon monoxide exposure: a clinical syndrome detected by neuropsychological tests. J Clin Psychol 1998;54:555-67.
10. Hopkins RO, Weaver LK, Kesner RP. Long-term memory impairments and hippocampal magnetic resonance imaging in carbon monoxide poisoned subjects. Undersea & Hyperbaric Med 1993;20 (4 Suppl):15.
11. Hopkins RO, Woon FL. Neuroimaging, cognitive, and neurobehavioral outcomes following carbon monoxide poisoning. Behav Cogn Neurosci Rev 2006;5:141-55.
12. Gale SD, Hopkins RO. Effects of hypoxia on the brain: neuroimaging and neuropsychological findings following carbon monoxide poisoning and obstructive sleep apnea. J Int Neuropsychol Soc 2004;10:60-71.
13. Hampson NB. Emergency department visits for carbon monoxide poisoning in the Pacific Northwest. J Emerg Med 1998;16:695-8.
14. German RR, Lee LM, Horan JM, Milstein RL, Pertowski CA, Waller MN; Guidelines Working Group, Centers for Disease Control and Prevention (US). Updated guidelines for evaluating public health surveillance systems: recommendations from the Guidelines Working Group. MMWR Recomm Rep 2001;50(RR-13):1-35.
15. Agency for Healthcare Research and Quality (US), Healthcare Cost and Utilization Project. On-line HCUP overview course [cited 2008 Oct 27]. Available from: URL: http://www.hcup-us.ahrq.gov/overviewcourse.jsp
16. AHRQ (US), HCUP. Design of the Nationwide Inpatient Sample (NIS), 2005 [cited 2008 Oct 27]. Available from: URL: http://www.hcup-us.ahrq.gov/db/nation/nis/reports/NIS_2005_Design_Report.pdf
17. AHRQ (US), HCUP. HCUPnet: HCUPnet overview [cited 2008 Oct 27]. Available from: URL: http://hcupnet.ahrq.gov/HCUPnet.jsp?Id=D07D26EB0C520319&Form=MAINSEL&JS=Y&Action=%3E%3ENext%3E%3E&HCUPnet%20Overview.x=1
18. Council of State and Territorial Epidemiologists. 2007 position statements: environmental health: updates to 1998 case definition for acute carbon monoxide poisoning surveillance [cited 2008 Oct 27]. Available from: URL: http://www.cste.org/position%20statements/searchbyyear2007final.asp
19. Research Triangle Institute. SUDAAN®: Version 9.0. Research Triangle Park (NC): Research Triangle Institute; 2005.
20. AHRQ (US), HCUP. HCUPnet: HCUPnet methodology [cited 2008 Oct 27]. Available from: URL: http://hcupnet.ahrq.gov/HCUPnet.jsp?Id=D07D26EB0C520319&Form=MAINSEL&JS=Y&Action=%3E%3ENext%3E%3E&HCUPnet%20methodology.x=1
21. National Center for Health Statistics (US). Estimates of the July 1, 2000–July 1, 2005, United States resident population from the Vintage 2005 postcensal series by year, county, age, sex, race, and Hispanic origin, prepared under a collaborative arrangement with the U.S. Census Bureau [cited 2010 Jan 4]. Available from: URL: http://wonder.cdc.gov/wonder/help/populations/bridged-race/Estimates2000-05.html
22. Census Bureau (US). Annual estimates of the population for the United States, regions, and states, and for Puerto Rico: April 1, 2000, to July 1, 2006 [cited 2008 Nov 18]. Available from: URL: http://www.census.gov/popest/states/tables/NST-EST2006-01.xls
23. AHRQ (US), HCUP. HCUP quality control procedures [cited 2008 Oct 27]. Available from: URL: http://www.hcup-us.ahrq.gov/db/quality.jsp
24. AHRQ (US), HCUP. HCUP: NIS related reports: HCUP data quality reports: 2005 [cited 2008 Oct 27]. Available from: URL: http://www.hcup-us.ahrq.gov/db/nation/nis/nisrelatedreports.jsp
25. AHRQ (US), HCUP. Introduction to the HCUP Nationwide Inpatient Sample (NIS), 2006 [cited 2008 Oct 27]. Available from: URL: http://www.hcup-us.ahrq.gov/db/nation/nis/2006NIS_INTRODUCTION.pdf
26. AHRQ (US), HCUP. HCUP: NIS related reports: E-code evaluation report: report #2004–2006 [cited 2008 Oct 27]. Available from: URL: http://www.hcup-us.ahrq.gov/db/nation/nis/nisrelatedreports.jsp
27. AHRQ (US), HCUP. HCUP: NIS related reports: NIS comparison report: 2005: report #2008–01 [cited 2008 Oct 27]. Available from: URL: http://www.hcup-us.ahrq.gov/db/nation/nis/nisrelatedreports.jsp
28. AHRQ (US), HCUP. HCUP 2005 Nationwide Inpatient Sample (NIS) now available [cited 2008 Sep 11]. Available from: URL: http://www.hcup-us.ahrq.gov/news/announcements/nis_05.jsp
29. AHRQ (US). Budget estimates for appropriations committees, fiscal year 2009: performance budget submission for congressional justification [cited 2008 Sep 16]. Available from: URL: http://www.ahrq.gov/about/cj2009/cjweb09.htm
30. Teutsch SM, Churchill RE, editors. Principles and practice of public health surveillance. 2nd ed. New York: Oxford University Press, Inc.; 2000.
31. Liebelt EL. Hyperbaric oxygen therapy in childhood carbon monoxide poisoning. Curr Opin Pediatr 1999;11:259-64.
32. Weaver LK. Clinical practice. Carbon monoxide poisoning. N Engl J Med 2009;360:1217-25.
33. WebMD. First aid & emergencies: carbon monoxide (CO) [cited 2009 Jul 8]. Available from: URL: http://firstaid.webmd.com/carbon-monoxide-co
34. Carbon monoxide poisonings associated with snow-obstructed vehicle exhaust systems—Philadelphia and New York City, January 1996. MMWR Morb Mortal Wkly Rep 1996;45(1):1-3.
35. Census Bureau (US). Census 2000, summary file 1(SF1), matrix P2 [generated by Shahed Iqbal using American FactFinder] [cited 2008 Oct 27]. Available from: URL: http://factfinder.census.gov
36. AHRQ (US), HCUP. Publications from the HCUP databases [cited 2007 Oct 9]. Available from: URL: http://www.ahrq.gov/data/hcup/hcupref.htm